6

AN INVESTIGATION

Into

THE RELATIVE VALUE OF AUTOMATIC CUT-OFF AND THROTTLE GOVERNING, AS INDICATED BY STEAM CONSUMPTION.

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This would seem to be a closed question as far as American practice is concerned. The more compact form of the shaft governor, and its greater freedom from accident, due to the absence of driving gears, have done much to commend it. In the matter of steam consumption, it is generally stated that the fact of the automatic cut-off governor using steam expansively more than counteracts the superheating of the throttle governor in its effect on the efficiency.

In the actual test, an effort was made to determine the truth of this assertion. The engine used was a Weston High Speed Automatic, built by the Weston Engine Company, of Painted Post, New York.

The dimensions were:-

Diameter of Cylinder . . .	8″
Length of Stroke	8″
Diameter of Piston Rod. . .	1 1/8″
Rated Horse Power	15

The engine was equipped with a centrifugal governor, a photograph of which is shown with the fly-wheel.

The weights shown fly out under the action of centrifugal force, this action being opposed by the springs. When the centrifugal force is sufficient to overcome the tension of the springs, the weights act on the levers to which they are pinned through the links shown, moving the eccentric across the shaft and thus shortening the valve travel. To permit of this action, the eccentric is freely suspended from a pivot on one of the arms of the fly-wheel.

The other governor used was a Gardner governor, of the common fly-ball type, a photograph of which is shown along with the general arrangement for driving it.. The balls move out under the action of centrifugal force and the links to which they are attached being pinned so as to act as levers, their other ends press down on a small shaft to which a balanced valve is attached. This valve being placed in the main steam pipe, controls the supply of steam to the engine. The pressure against which the centrifugal force acts is provided by a spring which presses on one end of a lever, the other end of which is fixed to the small shaft carrying the balanced valve. This pressure can be varied

by tightening or loosening a set screw which regulates the pressure on the spring.

In order to allow the engine to be run with the throttle governor, the weights of the shaft governor were prevented from acting by placing the blocks on the arms of the fly-wheel, which are shown in the photograph of the latter. These blocks oppose the moving out of the levers to which the weights are attached beyond a certain point. The distance which these levers are allowed to move determines the cut-off for the throttle governor, since it should not be less than that to which they would move if free under the heaviest load applied. If the reverse should be the case, the shaft governor would act and the test be thus useless.

At first the blocks were set so as to give one quarter (1/4) cut-off with the throttle governor. It was found, however, under the heavier loads that the shaft governor acted and the blocks were changed so as to give five-eighths (5/8) cut-off. Under this arrangement no tendency was observed for the shaft governor to act, even under the heaviest loads.

The driving of the throttle governor was effected by means of a belt driven directly from the shaft, as shown in the photograph. The main steam pipe was broken and a U shaped line of pipe put in at right angles to the old pipe. In the center of the upper arm of this U-shaped line a calorimeter, not shown in the photograph, was placed. In the centre of the lower arm the throttle governor was set so as to have its driving pulley in line with the outer end of the main shaft of the engine. It fortunately happened that the Gardner governor was designed to run at two hundred revolutions while the engine ran at about three hundred and forty. As the pulley of the governor was five inches in diameter and the shaft three inches, the desired reduction was effected without any further gearing.as 3 : 5 = 200 : 333.3 . The lubricator was connected across the vertical end of the piping while a second calorimeter was placed in the main steam pipe just above the throttle valve. The function of this calorimeter was to determine the quality of the steam after passing through the governor. The office of the first calorimeter was to determine the quality of the steam charged

against the engine.

The exhaust steam was taken care of by a surface condenser and was received in a tank and weighed after condensation.

An Ashcroft revolution counter indicated the number of revolutions, while the load was applied by means of a Prony brake.

METHOD OF CONDUCTING TESTS.

All readings were taken as nearly as possible at ten minute intervals. The water was allowed to run into buckets so as to prevent backing up in the condenser. At the moment of beginning the test the revolution reading was taken. The pipe carrying the condensed steam was taken from the bucket and placed in the tank, the zero reading of the tank scales having been previously taken. The upper and lower thermometers and pressure gauge of the upper calorimeter were then read, and the same readings were taken on the lower calorimeter during throttle tests. Indicator cards were then taken and the load on the brake kept constant. About one min-

ute before the time to take the next reading the pipe was taken out of the tank and placed in a bucket. Immediately after taking the revolutions the pipe was transferred to another bucket. The time of changing buckets was taken and the water in the first bucket was thrown into the tank and weighed with the water for the first ten minutes. The pipe was then put in the tank with the water that had flown into the second bucket. By means of this method the water consumption for every ten minutes was determined. As a check, these ten minute quantities were added together and compared with the total as found by subtracting the weight of the tank empty from the weight of the tank full.

INSTRUMENTS USED.

1. Head Indicator #3071 (Thompson)
2. Crank Indicator #3383 (Thompson)
3. Indicator Springs #3071 and #3383
4. Fairbanks Scales #661927 and #602695
5. Ashcroft Revolution Counter
6. Four Thermometers (Reading from 0° to 400° F.)
7. Williamson and Cassedy Gauges #189434 and #189436

CALIBRATION OF INSTRUMENTS.

The gauges were tested on a Crosby guage tester; the results being as given in the tables.

The indicator springs were calibrated with the aid of the gauge calibration curves, in the standard manner.

The results were as shown in the tables.

The scales were tested by observing the difference in the readings before and after a fifty pound standard weight was applied.

An error of one-half pound in fifty = 1%, was found in the brake scale #661927.

METHOD OF WORKING UP RESULTS.

The dimensions of the engine as used in the calculations were:-

Stroke	7.98″
Diameter.	6.″
Diameter of Piston Rod . .	1 1/8″
Area of Piston (Head) . .	28.27 sq. in.
" " " Crank . .	27.28 sq. in.

The engine constant for the head end is therefore:

$$\frac{7.98 \times 28.27}{12 \times 33000} = .000569$$

and for the crank end:

$$\frac{7.98 \times 28.27}{12 \times 33000} = .000550$$

These constants multiplied by the number of revolutions, the scale of the spring and the mean ordinate of the cards taken during the test give the horse-power.

For instance in the test of May 21, 1901, the mean head ordinate was .336″ while the mean crank ordinate was .188″, while the number of revolutions was 335.7

The head horse-power = $.336 \times 52.2 \times .000569 \times 335.7 = 3.34$

and the crank " = $.188 \times 51.94 \times .00055 \times 335.7 = \underline{1.80}$

The horse-power of the engine is 5.14

therefore 5.14 for this test; 52.2 and 51.94 being the scales of the head and crank springs, respectively.

In order to have a standard for comparison, the number of pounds of steam used was reduced to pounds of saturated steam at 100 lbs. gauge pressure, in every case. This was done by first finding the quality of the steam. A calori-

meter, as before stated, was placed in the main steam pipe. This consisted of a line of piping which had its origin in a plugged piece of one-half inch pipe fitted into the main steam pipe and threaded so as to be nearly in contact with the opposite side of the steam pipe. In this piece, sixteen quarter-inch holes were bored and the steam led through them to a diaphragm with a quarter-inch hole in the centre through which it was allowed to expand in the open air.

The temperature of the steam entering and leaving this arrangement was measured by two (2) four hundred degree thermometers. A gauge gave the steam pressure at entrance. This pressure in the test mentioned was 95.7. On consulting the calibration curve of the gauge (#189484), this was found to correspond to an actual pressure of 93.2 lbs. above atmosphere or a pressure of 93.2 + 14.7 = 107.9 lbs. absolute. In Peabody's steam tables this was found to correspond to a temperature of 333.13° F.

The average reading of the upper thermometer was 324.9°, and as this was obtained by changing the upper and

lower thermometer after every reading it was assumed that 333.13 - 324.9 = 8.25 represented the loss due to radiation. The calorimeter however was carefully lagged with hair felt.

The actual temperature of the steam leaving was therefore assumed to be 279.1 + 8.25 = 287.3.

The heats were now equated since the total heat is the same on both sides of the diaphragm less a slight loss due to radiation.

$$q + x\ r = q^1 + r^1 + .48\ (T_{sup} - T_{sat})$$

Where q is the heat of the liquid, x the proportion of steam to a pound of the mixture and r the number of heat units required to vaporize a pound of the liquid at the observed pressure, q^1 and r^1 are the same for the steam on the lower side, and since the pressure is that of the atmosphere, 14.7 lbs. being the mean, q will always be 180.8 and r 965.8. The last term is the number of degrees of superheating multiplied by the specific heat of steam at constant pressure, the steam becoming superheated from the sudden drop in pressure.

Proceeding as above described in the test mentioned and

taking our values from Peabody's tables:

$$303.7 + x \times 879.9 = 180.8 + 965.8 + .48\ (287.3 - 212)$$

$$\text{or } x = \frac{879.}{879.9} = .998$$

The total quantity of condensed steam received from the condenser was 282 lbs., the test having lasted for one hour. The total amount of dry steam used by the engine was therefore

$$282 \times .998 = 281.56$$

as the heat contained in the entrained water is of no value.

As the pressure varied in the different tests it was decided to reduce the steam consumption to terms of #100 gauge pressure, steam considered as dry and saturated. From the tables one pound of such steam has 1184.8 heat units in it. The number of pounds of such steam equal to the number of pounds of steam as used in the test is therefore $281.6 \times \frac{879.9 + 303.7}{1184.8} = \frac{1183.6}{1184.8} \times 281.6$

Also the number of pounds per horse-power hour was

$$\frac{1183.6 \times 281.6}{1184.8 \times 5.14} = 54.73$$

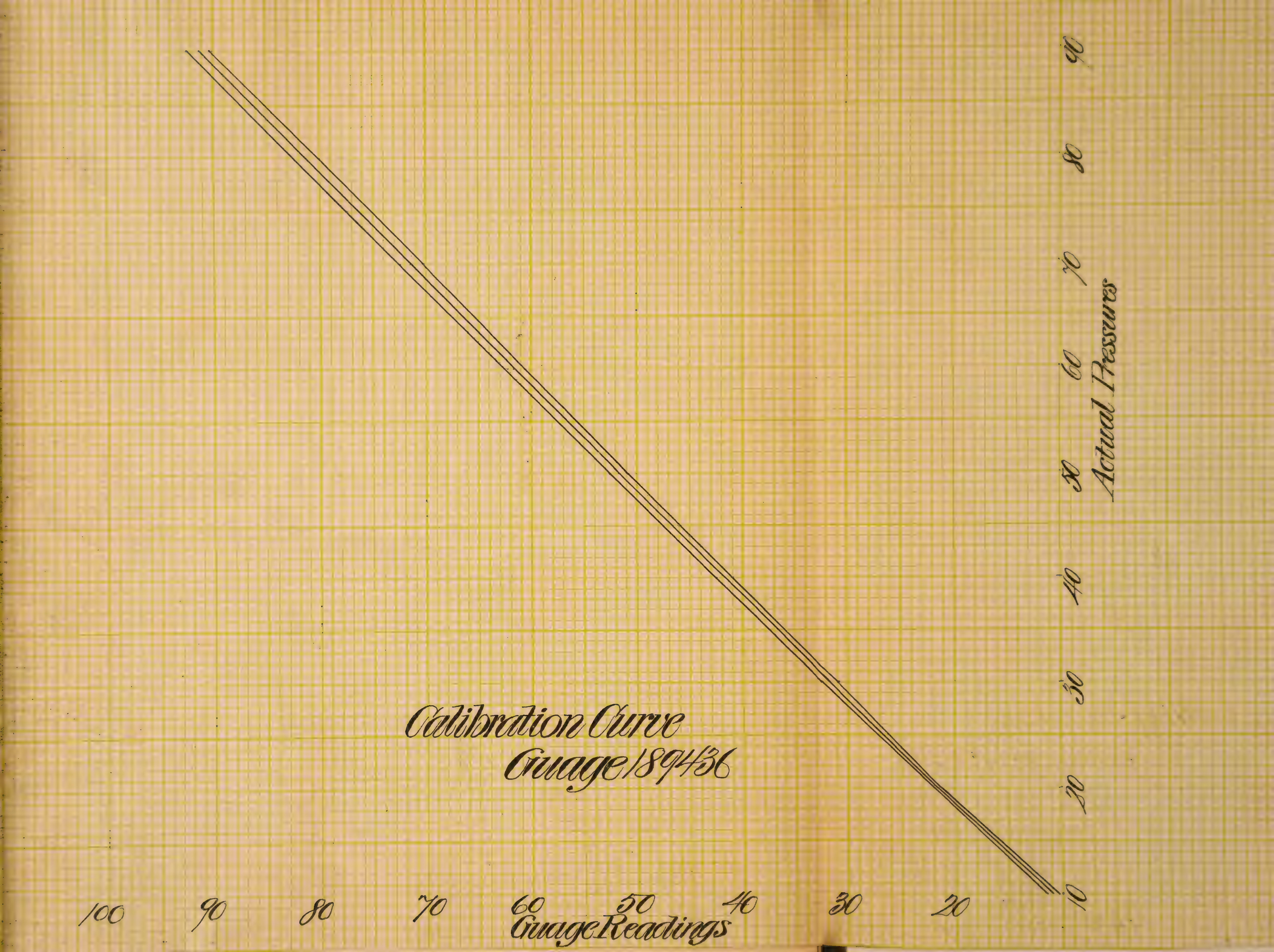
The lower calorimeter was used in the same way as the upper one as described, and its only object was to ascertain

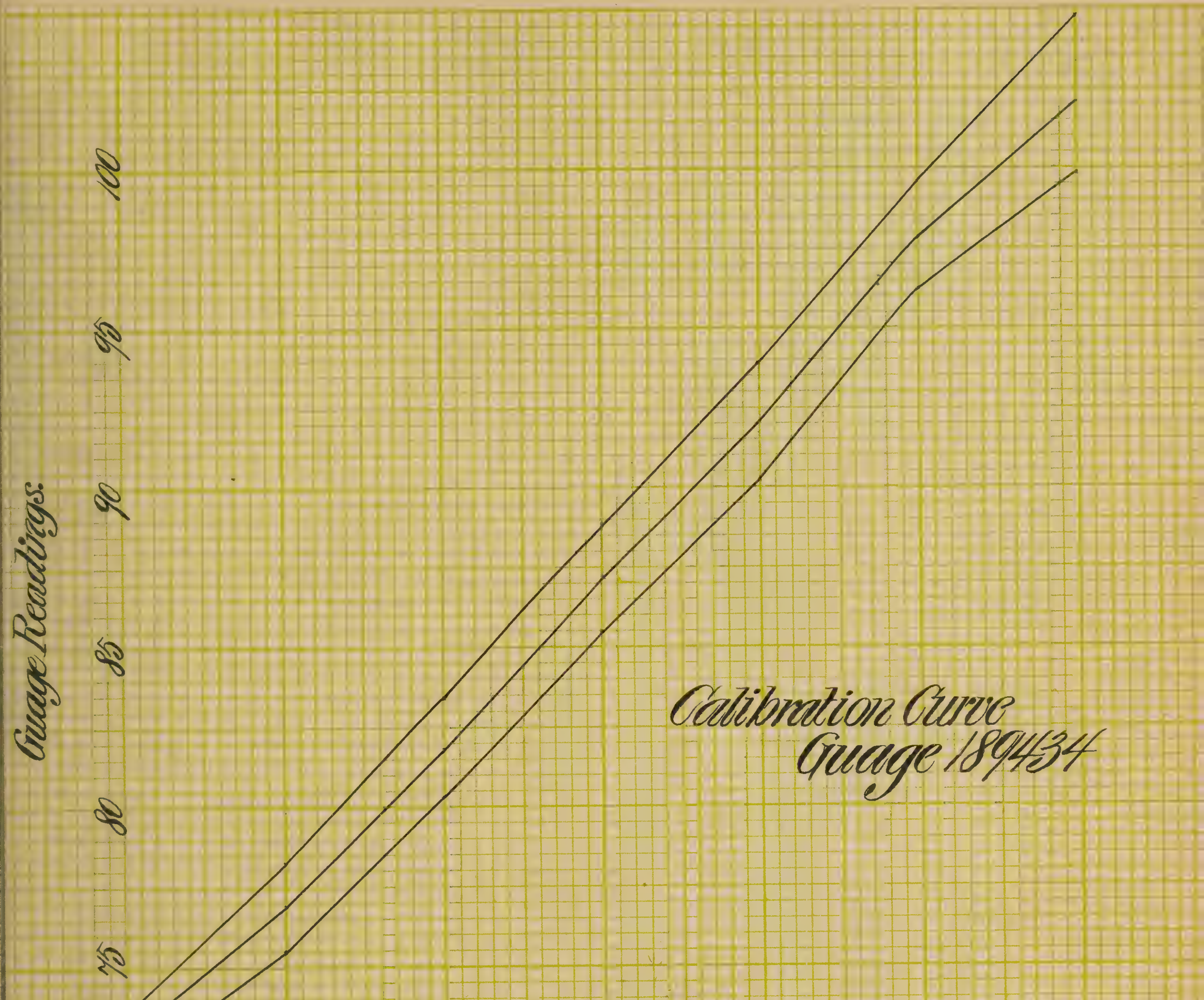
the extent of the superheating due to the throttle governor. The results of the observations on this were worked up in exactly the way described.

CONCLUSIONS

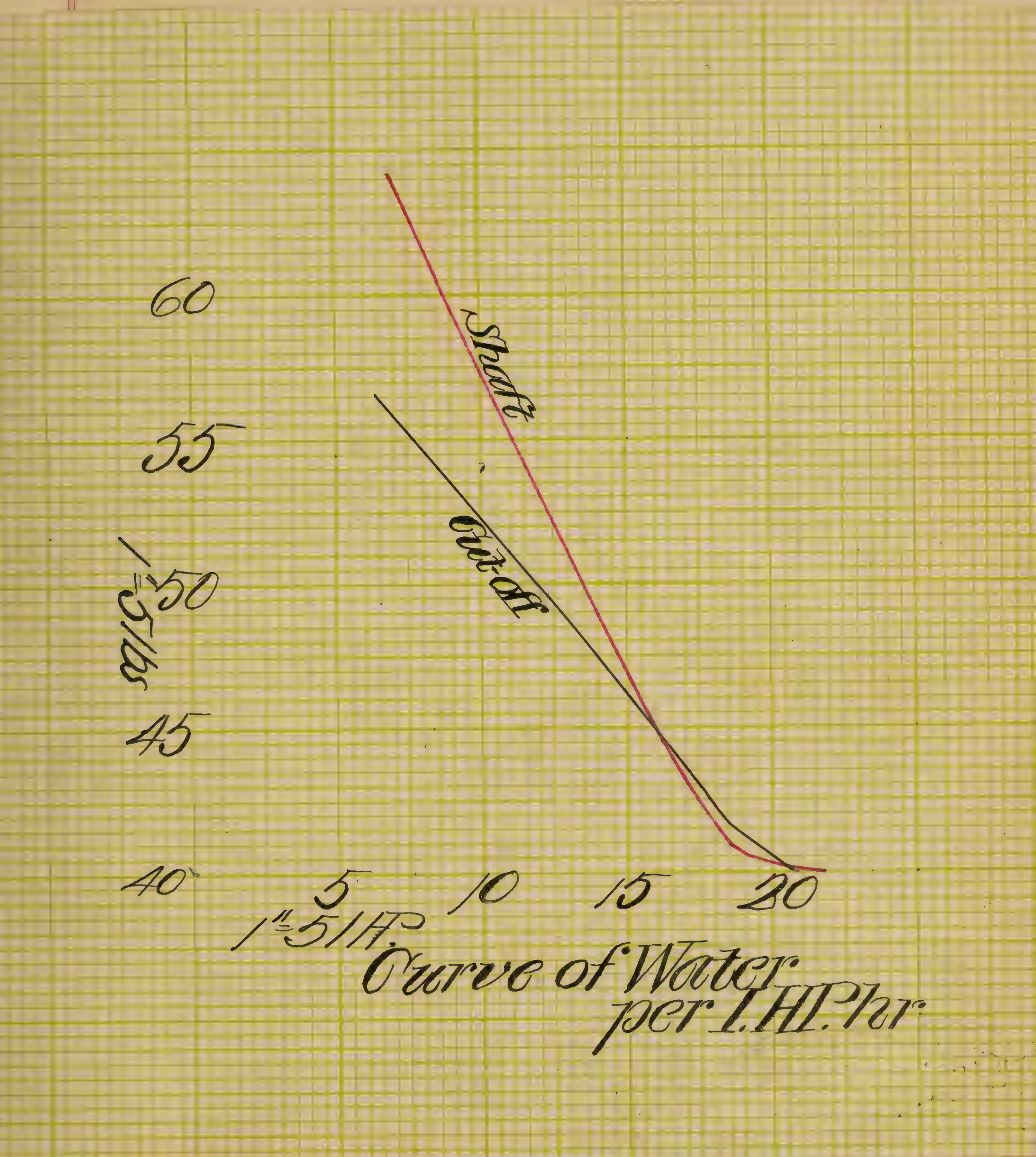
The curve of water consumption per one horse power hour shows pretty clearly the relative values. The water consumption under small loads is high in both cases. For medium loads the throttle would seem to excel while for heavy loads the two are about equal. It is to be remembered, however that at full load on the throttle governor the pressures both sides of the throttle valve are about equal, and the superheating is nil.Likewise with the cut off governor at very high loads the cut-off is late and conditions similar to those with the throttle governor. It was expected therefore that the water consumptions would be nearly equal.

In only one case was there superheating to any great extent, at the lowest load, and it may be stated that with this load and superheating the steam consumption was greater than with a similar load on the cut-off governor.


Calibration Curve
Guage 189436
100 90 80 70 60 50 40 30 20
Guage Readings
10 20 30 40 50 60 70 80 90
Actual Pressures



Guage Readings.
75
80
85
90
95
100
Calibration Curve
Guage 189434
70
75
80
85
90
95
100
Actual Pressures

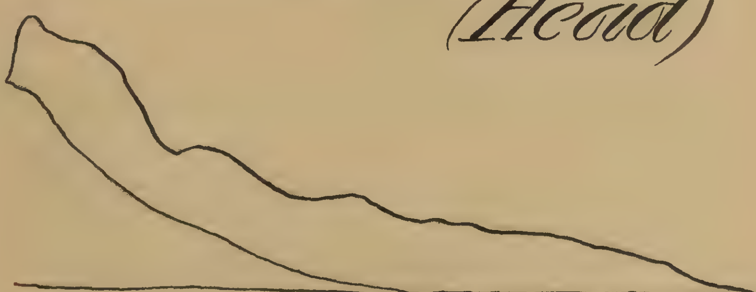

Shaft
Cut-off
60
55
50
45
40
1" = 5 lbs
5
10
15
20
1" = 5 I.H.P.
Curve of Water per I.H.P. hr

Test No. 1 May 21, 1901.

Time	Revs	R.P.M.	Water	Water per 10 Min.	T_1'	T_2'
10-55	8496	—	162	—	325	273
11-05	1864	337.8	215	53	324	277
11-15	5216	335.2	260	45	323	279
11-25	8604	338.8	305	45	325	281
11-35	2058	336.4	3.51	46	325	281
11-45	5324	335.6	398	47	326	282
11-55	8633	330.9	444	46	326	281
Totals		2014.7	282	282	2274	1954
Means		335.3			324.9	279.1

Automatic Brake 45

Sample Card (Head)

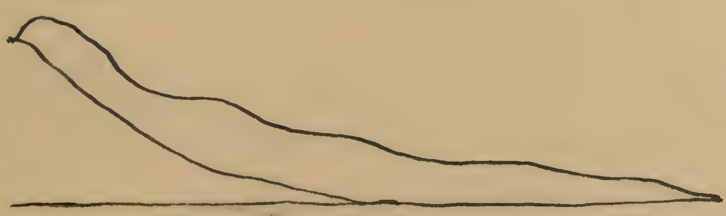


Test No. 1 May 21, 1901.

Press.	Time of Taking card	Mean ord. Head	Mean ord. Crank			
95	10.59	.374	.193			
95.5	11-10	—	.198			
94.5	11-19	—	—			
95.	11-28	.318	.176			
97.	11-39	.323	.170			
97	11-48	.349	.200			
96	11-57	.317	.194			
670		1.681	1.131			
95.7		.336	.188			

Automatic Brake 45

Sample Card
(Crank)



Test No. 2 May 23, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min	T_1	T_2
3-40	0168		217		279	324
3-50	3612	344.4	291	74	282	328
4-00	7052	344.0	367	76	282	330
4-10	0499	344.7	442	75	284	331
Totals		1033.1	225	225	1127	1313
Means		344.3			281.7	328.2

Throttle Brake 60

Test No 2 May 23, 1901

T_1'	T_2'	P_{upper}	P_{lower}	Time of Taking card	Mean ord. Head	Mean ord. Crank
224	270	99	26	3-44	.398	.353
236	270	98	25	3-56	.364	—
232	269	97	26	4-08	.392	.270
233	271	99.5	30	4-14	.425	.276
925	1080	393.5	107		1.579	.899
231.2	270	98.4	26.7		.3947	.2996

Throttle Brake 60

Test No. 3 May 23, 1901

Time	Revs.	R.P.M.	Water	Water per 10 Min.	T_1	T_2
2-55	4412	333.3	153		324	270
3-05	7745	333.6	226	73	325	281
3-15	1081	331.3	293	67	328	281
3-25	4394	331.6	361	68	325	280
3-35	7710	333.2	425	64	328	281
3-45	1042	331.2	491	66	328	284
3-55	4354		556	65	330	282
Totals		1994.2	403	403	2288	1959
Means		332.3			326.9	279.9

Automatic Brake 60

Test No. 3 May 23, 1901.

Press.	Time of Taking Card	M.E.P. Head	M.E.P. Crank
98	2-59	.498	.397
99	3-09	.487	.386
97	3-18	.509	.452
96	3-27	.520	.397
98	339	.505	.414
99	4-49	.537	.456
100	4-59	.557	.446
687		3.613	2.948
98.1		.516	.421

Automatic Brake 60

Test No 4 May 23, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min	T_1	T_2
4-40	3952			—	327	284
4-50	7296	334.4	150	116	323	283
5-00	.0644	334.8	266	114	323	282
5-10	4049	340.5	380	114	329	284
			494			
Totals		1019.7	344	344	1302	1133
Means		339.7			325.5	283.2

Throttle Brake 85

Test No 4 May 23, 1901

T'_1	T'_2	P_{upper}	P_{lower}	Time of Taking Card	Mean ord. Head	Mean ord. Crank
288	247	95	52	4-45	.806	.966
296	257	96	53	4-58	.757	.698
296	257	97	53	5-07	.750	.799
290	254	98	50	5-14	.697	.773
1170	1015	386.5	208		3.010	3.236
292.5	253.7	96.5	52		.752	.809

Throttle Brake 85

Test No. 5 May 20, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min.	T_1	T_2
3-30	1406	—	212	—	327	276
3-40	4712	330.6	315	103	326	279.5
3-50	8045	333.3	401	86	330	276
4-00	1364	331.9	483	82	328	277
4-10	4662	329.8	577	94	323	278
4-20	8024	336.2	661	84	330	274
4-30	1368	334.4	416 506	90	326	280
Totals		1996.2	539	539	2290	1945
Means		332.5			327.1	277.8

Automatic Brake 95.

Test No. 5 May 20, 1901

Press	Time of Taking Card	Mean ord. Head	Mean ord. Crank			
96	3-37	.522	.502			
98	3-44	.566	.483			
99	3-56	.506	.476			
97.5	4-07	.558	.499			
93.5	4-14	.573	.519			
101.	4-29	.525	.462			
100.	4-34	.566	.521			
685		3.816	3.462			
97.8		.545	.494			

Automatic Brake 95

Test No. 6 May 25, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min.	T_1 upper	T_2 upper
12-05	3660	—	160	—	338	267
12-15	7049	338.9	250	90	324	279
12-25	0504	345.5	337	87	326	280
12-35	3886	338.6	426	89	323	280
12-45	7202	331.6	513	87	320	277
12-55	0516	331.4	607	94	324	268
1-05	3942	342.6	714	107	325	269
Totals		2028.6	544	544	2280	1920
Means		338.1			325.7	274.3

Throttle Brake 90

Test No. 6 May 25, 1901

T_1 lower	T_2 lower	P upper	P lower	Time of Taking Card	Mean ord. Head	Mean ord. Crank
309	263	92	68	12-09	.665	.593
299		95	56	12-19	.575	.515
298		95.2	54	12-28	.542	.568
311		86	71	12-37	.654	.607
316		84	70	12-48	.704	.700
303	255	87	60	12-59	.692	.692
306	260	85	68	1-09	.736	.849
2142	778	624.2	447		4.568	4.524
306	259.3	89.2	63.8		.653	.646

Throttle Brake 90

Test No 7 May 26, 1901

Time	Revs.	R.P.M.	Water.	Water per 10 Min.	T_1 upper Calorim.	T_2 upper Calorimeter
2-55	8528		156		325	268
3-05	1895	336.7	284	128	327	278
3-15	4268	337.3	397	113	328	281
3-25	7602	333.4	525	128	329	281
3-35	1044	344.2	654	129	326	280
3-45	4438	339.4	294 410	116	326	280
3-55	7799	336.1	498	88	329	280
Totals		2027.1	702	702	229.1	1948
Means		337.8			327.1	278.2

Throttle Brake 110

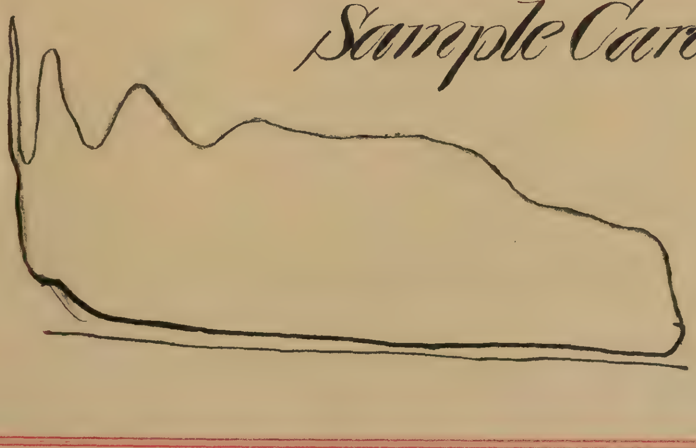
Sample Card
(Crank)

Test No 7 May 26, 1901

$T_{lower\ Cyl.}$	$T_{2\ lower\ Cyl.}$	$P_{upper\ Cy.}$	$P'_{lower\ Cy.}$	Time of Taking Cards	M.E.P. Head	M.E.P. Crank
303	243	96	67	2-59	.979	.835
300	255	98	64	3-11	.921	.833
298	258	97.5	63	3-20	.924	.827
302	254	97.	64	3-31	.885	.856
300	256	97.	65	3-39	.906	.832
309	257	98.	65	3-50	.943	.826
301	256	99.	64			
2113	1779	682.5	452		5.458	5.009
301.8	254.1	97.5	64.5		.909	.835

Throttle Brake 110

Sample Card (Head)



Test No 8 April 29, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min.	T_1 upper	T_2 upper
11-50	832	334.6	192	—	325	261
12-00	4178	334.4	292	100	326	269
12-10	7522	332.5	390	98	323	266
12-20	847	335.4	487	97	328	267
12-30	4201	334.3	590	103	324	275
12-40	7544	334.5	692	102	325	276
12-50	889	—	2024.5 334.5	110	327	274
Totals		2005.7	610	610	2278	1888
Means		334.3			325.4	269.7

Automatic Brake 110

Test No. 8 April 29, 1901

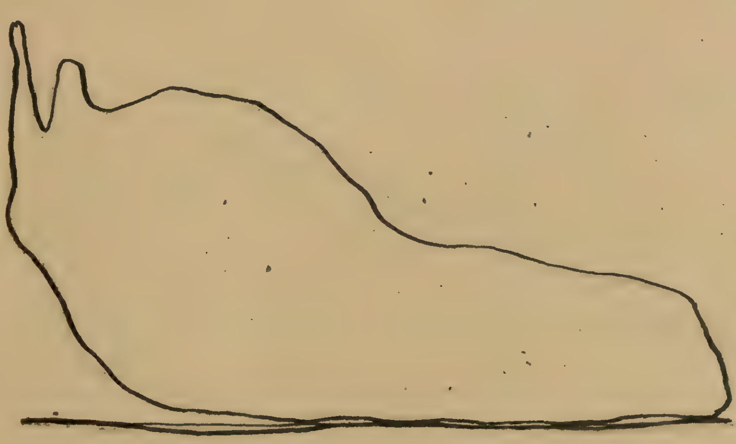
Press	Time of Taking Cards	Mean ord. Head	Mean ord. Crank
98	11-54	.608	.598
99	12-06	.590	.566
97	12-14	.642	.598
95	12-26	.634	.567
97	12-34	.666	.581
97	12-45	.732	.611
94	12-59	.778	.718
677		4.650	4.239
96.7		.664	.605

Automatic Brake 110

Test No. 9 May 22, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min	T_1	T_2
1-20	2906	293.	162	—	323	268
1-30	5836	324.8	305	143	326	275
1-40	9084	326.4	449	144	324	280
1-50	2340	326.9	588	139	328	278
2-00	5609	326.3	642 324	127	329	279
2-10	8872	325.6	399 535	136	326	280
2-20	2128		676	141	326	278
Totals.		1923	830	830	2282	1938
Means.		320.5			326	277

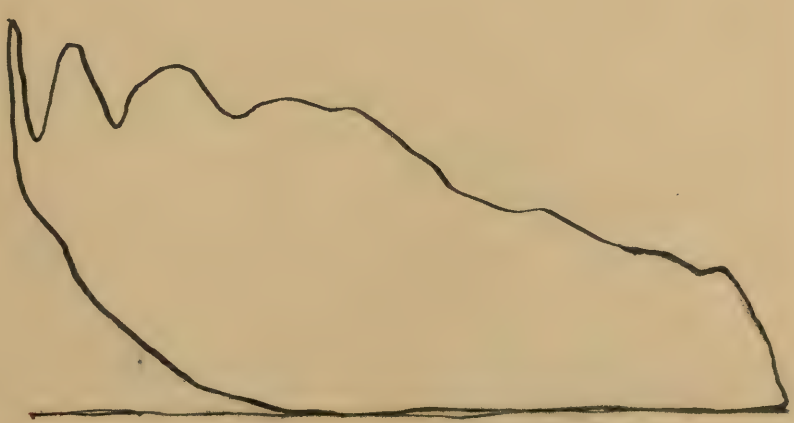
Automatic Brake 135



Test No. 9 May 22, 1901

Press	Time of Taking Card	Mean Ord. Head	Mean Ord. Crank			
95	1-27	1.245	1.145			
96	1-34	1.185	1.055			
96	1-45	1.137	.994			
98	1-55	1.183	1.045			
98	2-04	1.170	1.067			
100	2-15	1.115	.918			
98	2-29					
681		7.035	6.254			
97.3		1.173	1.042			

Automatic Brake 135



Test No. 10 May 24, 1901

Time	Revs	R.P.M.	Water	Water per 10 Min.	T_1 upper	T_2 upper
4-40	8749	—	153	—	330	278
4-50	2046	329.7	297	144	328	281
5-00	5328	328.2	444	147	329	280
5-10	8625	329.7	603	159	330	281
5-20	1932	330.7	714 373	111	328	280
5-30	5286	335.4	520	147	330	281
5-40	8492	320.6	680	160	328	279
Totals			868	868	2303	1960
Means					329	280

Throttle Brake 135

Test No 10 May 24, 1901

T_1 lower	T_2 lower	P upper	P lower	Time of Taking Cards	Mean ord Head	Mean ord Crank
310	263	96	86	4-47	1.095	1.025
313	264	97	87	4-54	1.107	1.025
311	264	97	86	5-06	1.231	1.052
310	263	98	86	5-14	1.027	.987
311	264	97	87	5-24	1.213	1.107
318	266	97	85	5-34	1.243	1.155
319	267	98	87	5-43	1.243	1.125
2192	1851	680	604		8.159	7.476
313.1	264.4	97.1	86.3		1.165	1.068

Throttle Brake 135

Guage #189436 May 18, 1901			
Weight	Ascend.	Descend	Mean
10	10.2	11.5	10.85
15	16.1	17.1	16.6
20	21.2	22.	21.6
25	25.9	27.6	26.75
30	30.9	32.4	31.65
35	35.9	37.5	36.7
40	41	42.3	41.65
45	46.1	47.7	46.9
50	50.9	52.4	51.6
55	55.6	57.4	56.5
60	60.5	62.1	61.3
65	65.2	67.4	66.3
70	70.1	72.3	71.2
75	75.1	77.5	76.3
80	80.	82.4	81.2
85	85.05	87.1	86.07
90	90.2	92.5	91.3

Guage #189434 May 18, 1901			
Weight	Ascend.	Descend.	Mean
70	71.9	73.5	72.7
75	75.5	78.2	76.8
80	80.4	83.4	81.9
85	85.4	88.9	87.1
90	90.2	93.9	92.05
95	96.2	99.5	97.8
100	99.8	103.8	101.8

Results of Tests

No.	Gov.	I.H.P.	Water per IHP hr.	Quality of Steam #1	Quality of Steam #2
1	Automatic	5.14	54.77	.998	
2	Throttle	6.98	64.48	.9991	3.4° Sup.
3	Autom.	9.07	44.39	.9991	—
4	Throttle	15.18	45.3	.999	.999
5	Autom.	10.05	53.5	.9974	—
6	Throttle	12.79	41.9	.9952	.9939
7	Autom.	12.36	49.08	.994	—
8	Throttle	17.19	40.73	.9975	.9935
9	Autom.	20.61	40.09	.999	
10	Throttle	21.45	40.36	.9974	.9955

(#1) Is quality as indicated by the upper Calorimeter

(#2) Is quality as indicated by the lower Calorimeter.